151383 RAM

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION III
841 CHESTNUT BUILDING
PHILADELPHIA, PENNSYLVANIA 19107

FAX TRANSMITTAL

PAGE 1 OF 5

DATE: ~~7-11-96~~ 7-18-96

PROJECT: Westinghouse (Sharon)

PLEASE DELIVER AT ONCE TO:

NAME: Charles Tordella

FIRM NAME: PA DEP (HSCA)

PHONE:

FAX NUMBER: 814-332-6121

FROM: Vic Janosik

PHONE: 215-566-3217

FAX NUMBER: 215-566-3001

COMMENT/NOTE: Enclosed are comments on Preliminary Risk documents by Jennifer Hubbard. I'll be in Touch

Vic

AR302710

KHM

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
841 Chestnut Building
Philadelphia, Pennsylvania 19107

SUBJECT: Review of Risk Assessment Exposure Factors: Westinghouse-Sharon

DATE: 7/10/96

FROM: Jennifer Hubbard, Toxicologist JRHubbard
Technical Support Section (3HW41)

TO: Vic Janosik, RPM
Western PA Remedial Section (3HW22)

The following three packets of material were reviewed: Well Grouping, Revised Human Health and Ecological Risk Receptor Characterization, Exposure Factor Tables. Additionally, I spoke with Geoff Bristow of PADEP and Mark Maritato of ChemRisk, both on 7-10-96, in order to understand some of the rationale behind well selection, and to understand some of the assumptions that had gone into the development of these factors. Comments are listed below.

WELL GROUPING

1. It is understood that within each plume area, all COPCs will be evaluated. (For example, within the southern plume, more than just VOCs will be evaluated.)

2. The wells in the LNAPL area are not included for quantitative risk assessment. This is acceptable if the EPA RPM has sufficient information on this area to establish the need for remedial action, evaluate alternatives, and set cleanup levels. (This is likely to be the case, since a removal action has already been triggered for the LNAPL.)

3. It is not clear why being "in close proximity to the Sawhill Tubular remediation area" and "at least 500 feet from the Westinghouse property" were part of criteria for well elimination. Selecting the most contaminated areas (exclusive of the LNAPL area), as has been done, should be sufficient.

4. It is recommended that the following wells be added to the central plume: MW-15B, MW-3B, and MW-11B, due to high total concentrations of chemicals.

   MW-3B has been suggested mostly because of VOCs. There appears to be a second VOC plume in the middle of the site, although it is already covered by many of the central plume wells, except MW-3B. Although M-16, MW-17AR, and N-3A might also be related to this plume, their concentrations are much lower and these three wells may be factors more in the nature and extent rather than in the quantitative risk estimate.

PCBs have also been found in wells S-4, S-6, S-3, S-7, S-9, S-10, S-11, S-8A, and N-7AR. However, their concentrations are much lower than in the central plume, and these nine wells may be factors more in the nature and extent rather than in the quantitative risk estimate. A similar condition exists with respect to dioxins/furans in N-3A, N-7AR, and N-2A.

RECEPTOR CHARACTERIZATION

5. Risks from fish tissue ingestion should be estimated. Ideally, this exposure should be quantitated. However, in the absence of validated data, semiquantitative or qualitative discussion should be included.

6. A semiquantitative or qualitative discussion of the effects of the river contamination on the downstream water intake should be included.

EXPOSURE FACTOR TABLES

7. The residential exposure to groundwater should include a child as well as adult. For carcinogenic risks, these are combined; for noncarcinogenic risks, they remain separate. The child is assumed to have oral and dermal (from bathing) but not inhalation exposure to the groundwater.

8. Region III recommends the Foster and Chrostowski, 1987, model for showering, using the following inputs:

   Inhalation rate: 14 L/min
   Rate of air exchange: 0.01667/min
   Duration of shower: 12 min
   Total time in shower room: 20 min
   Shower flow rate: 20 L/min (prof. judgment)
   Shower room volume: 6 m^3
   Shower droplet diameter: 1 mm
   Drop time: 2 sec
   T1 (calibration water temp.): 293 K
   Ts (shower water temp.): 318 K
   Water viscosity at T1: 1.002 centipoise
   Water viscosity at Ts: 0.596 centipoise
   Henry's Law constant: chemical-specific
   Molecular weight: chemical-specific

   The Foster and Chrostowski paper is attached.

9. It is not clear whether the depth of the river allows swimming as well as wading; this should be considered.

10. For the wader: The fraction of skin exposed was not labeled as relating to surface water or sediment. It is understood to be for sediment, based on a telephone conversation with Mark Maritato (7-10-96).

11. This paper does not specify which dermal exposure equation will be used. EPA recommends the steady-state equation found in RAGS for soil/sediment exposure, and the non-steady-state equation found in the 1992 Dermal Exposure Assessment document for water. If using the latter, the factors B, t*, and tau must also be used as well as the permeability coefficient, but these chemical-specific factors are easily found in Table 5-8 of that guidance. Mark Maritato stated that he believed the steady-state model would be used for surface water. In such cases, a qualifying statement should be included that this is less conservative than the non-steady-state model for organics.

12. I believe the default PEF has been updated as shown in the new Soil Screening Guidance (1.3E9). However, since this is for a 1/2-acre site that is 50% covered, it may be more desirable to use site-specific factors for site area and % cover.

13. Once per month or even once per week in outdoor months may be more realistic for maintenance workers, especially if property is redeveloped and regular maintenance of vegetation is needed.

14. The default for worker soil ingestion is 50 mg/day rather than 100 mg/day. This would apply for nonintrusive construction work as well; for intrusive construction work, factors as high as 480 mg/day (for short duration) should be used. (EPA's Standard Default Exposure Parameters, march 25, 1991).

15. Please provide more information on the construction worker scenario that will be used for the construction PEF; will the scenario be remedial or will it be applicable to regular construction work?

16. For construction workers, the averaging time for the 2-year noncarcinogen exposure should be 365 days/year X 2 years.

17. For groundwater, the amount that volatilizes out of the water should be subtracted from the total concentration when estimating dermal exposure during showering. This avoids "double-counting" the contaminant exposure and can be easily done when using the Foster and Chrostowski method, since factor C_{wd} is "concentration leaving water droplet" (that is, volatilizing out).

I have been in contact with Mary Ellen Schultz, the CRL chemist who has been looking at the data validation. A validation package is on its way to us; she will compare the original validation with the ESAT report so that we may estimate the usability of the data and determine our next steps in this respect.

If you have any questions concerning this review, please contact me at 215-566-3328. I suggest that once these comments have been received and reviewed by Westinghouse's representatives, we see if we can resolve any outstanding issues by having a conference call and documenting the results of the call, rather than undergoing an additional comment-response round. Please let me know if you agree.

Attachment

cc: Eric Johnson (3HW41; w/o attach.)
Bill McKenty (3HW41; w/o attach.)
Barbara Okorn Root (3HW41; w/o attach.)
David Turner (3HW22)

87-42.6

INHALATION EXPOSURES TO VOLATILE ORGANIC CONTAMINANTS IN THE SHOWER

SARAH A. FOSTER
PAUL C. CHROSTOWSKI

ICF-CLEMENT ASSOCIATES, INC.
WASHINGTON, D. C.

APCA FOUNDED IN 1907
The Association Dedicated to Air Pollution Control and Hazardous Waste Management

**For Presentation at the
80th Annual Meeting of APCA
New York, New York
June 21-26, 1987**

INTRODUCTION

Over the past few years, the potential importance of inhalation xposures to volatile organic chemicals (VOCs) through the use of contaminated usehold water supplies has been recognized. Due to their strong tendency to olatilize, VOCs present in tap water may be readily released into indoor air s a result of showering, bathing, dishwashing, laundering, and ooking.[1,2,3] Several researchers have already concluded that inhalation xposures to volatile compounds released during typical water uses in the home y be as large as or larger than exposures from water ingestion.[1,3,4,5,6] f particular concern to human health is the potential for elevated VOC xposures to occur in the confined space of the shower. Detailed empirical ata on the levels of VOCs released into shower room air are, however, carce.[1,7] Andelman and his colleagues, relying on experiments conducted sing trichloroethylene and chloroform in a scaled-down model shower, are esponsible for the bulk of the data that are currently available.

Exposure modeling may provide the best means of estimating inhalation xposures to VOCs while showering. Such modeling can be validated to a imited extent at present using Andelman's data and will be further validated the future with whatever reliable data become available.

The purpose of this paper is to expand on previous work in which we eveloped a dynamic model for the behavior of VOCs in shower water.[8] In is paper we present a model that estimates exposures to VOCs in the shower, oth while showering and after the shower has been turned off. The model has een programmed using Microsoft C and is run on an IBM PC. Typically a model n, including data input, takes less than one minute.

Previous efforts to estimate exposures to VOCs in the shower have relied on the simple assumption that a certain percentage of VOC in water is leased into air (e.g., 40-100%).[2,4,5] Our model, unlike the previous proaches, takes into account many of the variable factors that influence the lease of VOCs from water and their subsequent buildup in shower room air. e kinetic model presented in this paper estimates VOC air concentrations and e magnitude of chemical exposures for the duration of exposure.

THODOLOGY

Inhalation exposures to VOCs are modeled by estimating the rate of emical release into the air (generation rate), the buildup (shower on) and cay (shower off) of VOCs in shower room air, and the quantity of airborne Cs inhaled while the shower is both on and off.

Estimation of the rate of VOC release into the air is based upon Liss d Slater's[9] adaptation of the two-film gas-liquid mass transfer theory ich has been described in our previous paper.[8] The two-film boundary eory provides the basis for estimating the overall mass transfer coefficient L for each VOC of interest according to the following equation:

AR302716

$$K_L = (1/k_l + RT/Hk_g)^{-1} \quad (1)$$

where

K_L = overall mass transfer coefficient (cm/hr),
H = Henry's Law Constant (atm-m^3/mol-K), ille
RT = 2.4×10^{-2} atm-m^3/mole (gas constant of 8.2×10^{-5} atm-m^3/mol-K times absolute temperature of 293 K),
k_g = gas-film mass transfer coefficient (cm/hr), and
k_l = liquid-film mass transfer coefficient (cm/hr).

Equation 1 describes the mass transfer rate of a compound at an air-water interface where diffusion may be limited by both liquid- and gas-phase resistances. For most VOCs, however, with Henry's Law Constants greater than 1×10^{-3} atm-m^3/mol-K, mass transfer is limited by only liquid-phase resistance.[10]

Typical values of k_l (20 cm/hr) and k_g (3,000 cm/hr), which have been measured for CO_2 and H_2O, respectively,[9] may be used to estimate VOC-specific values for these parameters:

$$k_{g(VOC)} = k_g(H_2O)(18/MW_{VOC})^{0.5} \quad (2)$$

$$k_{l(VOC)} = k_l(CO_2)(44/MW_{VOC})^{0.5} \quad (3)$$

where

MW = molecular weight (g/mol).

The mass transfer coefficient, K_L, is adjusted to the shower water temperature, T_s, according to a semi-empirical equation developed to estimate the effect of temperature on oxygen mass-transfer rate:[11]

$$K_{aL} = K_L(T_l\mu_s/T_s\mu_l)^{-0.5} \quad (4)$$

where

K_{aL} = adjusted overall mass transfer coefficient (cm/hr),
T_l = calibration water temperature of K_L (K),
T_s = shower water temperature (K),
μ_l = water viscosity at T_l (cp), and
μ_s = water viscosity at T_s (cp).

The concentration leaving the shower droplet, C_{wd}, is obtained from an integrated rate equation based on a mass-balance approach:

$$C_{wd} = C_{wo}(1-\exp[-K_{aL}t_s/60d]) \quad (5)$$

where

C_{wd} = concentration leaving shower droplet after time t_s (µg/l),
C_{w0} = shower water concentration (µg/l),
d = shower droplet diameter (mm), and
t_s = shower droplet drop time (sec).

The term $K_{al}/60d$ combines both the rate of transfer and the available interfacial area across which volatilization can occur. The value 1/60d equals the specific interfacial area, 6/d, for a spherical shower droplet of diameter d multiplied by conversion factors (hr/3600 sec and 10 mm/cm).

Inherent in equation 5 is the assumption that the shower water is immediately disaggregated into droplets of equal size and that volatilization occurs from each droplet only between the time it is released from the shower head until it impacts the shower bottom. In reality, the shower water will disaggregate into droplets of different diameters and will also agglomerate into layers as it runs over the showering individual and impacts nearby surfaces. The model presented in this paper does not take into account volatilization from these "non-droplet" air-water surfaces, many of which increase the residence time during which volatilization could occur (relative to an unimpeded droplet). In addition, this model does not estimate the additional volatilization from water as it drains from the shower bottom. Volatilization from water running over a showering individual and draining from the shower bottom may, however, contribute significantly to overall VOC air concentrations in the shower.[12] By not taking into account volatilization from water running down nearby surfaces and the showering individual and draining from the shower bottom, our model is more likely to underestimate than overestimate indoor VOC air concentrations and exposures.

The VOC generation rate in the shower room, S, can then be calculated by the equation:

$$S = C_{wd}(FR)/SV \qquad (6)$$

where

S = indoor VOC generation rate (µg/m³-min),
FR = shower water flow rate (l/min), and
SV = shower room air volume (m³).

A simple one-box indoor air pollution model was used to estimate VOC air concentrations in the shower room. This model can be expressed as a differential equation describing the rate of change of the indoor pollutant concentration with time:

$$dC_a/dt = -RC_a + S \qquad (7)$$

where

C_a = indoor VOC air concentration (µg/m³), and
R = air exchange rate (min⁻¹).

This indoor air model assumes instantaneous mixing of the shower room air and no chemical decay of VOCs once they are released into the indoor air. It is likely, however, that air concentrations of VOCs will be higher immediately adjacent to the shower spray (i.e., within the individual's breathing zone) than in the rest of the shower room. As a result, the model may underestimate inhalation exposures during showering by assuming a completely mixed indoor environment. Because modeling the incremental exposure due to showering only is the focus of this paper, it is also assumed that the initial VOC air concentration indoors before the shower is turned on is zero (i.e., there are no other sources of VOCs contributing to indoor air pollutant levels).

In the model, the air exchange rate is kept constant throughout the exposure period. The generation rate is allowed only two values, off (i.e. zero) and on. In general, both the air exchange rate and the generation r[illegible] may vary over time; however, for the short periods modeled in this paper [illegible]more than one or two hours), we consider that the assumptions of const[illegible] exchange and generation rates are likely to be valid.

When equation 7 is integrated, the time-dependent indoor concentra[illegible] can be estimated as follows:

$$C_a(t) = (S/R)(1 - \exp[-Rt]) \text{ for } t \le D_s$$

and

$$C_a(t) = (S/R)(\exp[RDs] - 1)\exp(-Rt) \quad \text{for } t > D_s$$

where

$C_a(t)$ = indoor air VOC concentration at time t (µg/m³),
D_s = shower duration (min), and
t = time (min).

The inhalation exposure per shower can then be calculated according to the equation:

$$E_{inh} = [Vr/(BW)(10^6)] \int_0^{D_t} C_a(t)dt$$

where

E_{inh} = inhalation exposure per shower (mg/kg/shower),
VR = ventilation rate (l/min),
BW = body weight (kg), and
D_t = total duration in shower room (min).

This equation can be solved as:

$$E_{inh} = (Vr)(S)/[(BW)(R)(10^6)]\left(D_s - 1/R + \exp(-RD_s)/R\right)$$

for the duration of the shower, and as:

$$E_{inh} = (Vr)(S)/[(BW)(R)(10^6)]\cdot$$
$$\left(D_s + \exp(-RD_t)/R - \exp[R(D_s - D_t)]/R\right)$$

for both the duration of the shower and the duration in the room after the shower is turned off.

MODEL APPLICATION I. COMPARISON WITH EXPERIMENTAL RESULTS

The only experimental data currently available and sufficiently detailed to apply in our model have been developed by Andelman et al.[1] Experimental data presented by these researchers for trichloroethylene (TCE) were input into our model (Table I) to predict indoor air concentrations and to compare these with the measured levels. Figure I shows that our model's estimates of air concentrations compare favorably with Andelman's results for both the buildup and decay of concentrations in shower room air. The model only slightly underpredicts indoor air concentrations. This difference is not surprising since the model does not, as has been described, take into account volatilization from water after it has impacted on nearby surfaces or as it drains from the shower bottom. This comparison also indicates that for short exposure periods (e.g., less than 20 minutes), the modeled air concentrations may approximate actual concentrations quite well.

MODEL APPLICATION II. SENSITIVITY OF AIR CONCENTRATIONS TO INPUT PARAMETERS

To determine the sensitivity of our model to several important input parameters, we examined the changes in estimated air concentrations associated with different air exchange rates, shower water concentrations, and water temperatures. We focused on only one VOC, TCE, in this model application. Cothern et al.[4] estimate that as many as 212,000 and 128,000 individuals in the United States may be using public water supplies containing >10-20 μg/l and >70-80 μg/l TCE, respectively. To make our results comparable with these estimates, we assumed two shower water concentrations of 15 μg/l and 75 μg/l. Three air exchange rates, 0.5, 1.0, and 1.5 hr^{-1}, were used to simulate leaky, average, and tight homes, respectively.[13] The changes in air concentrations associated with four shower water temperatures, 35°, 40°, 45°, and 50°C, were also evaluated. Table II lists the values of the input parameters used to develop the information presented in this sensitivity analysis (Figures II and III).

Figure II illustrates the effects of changing air exchange rates and TCE water concentrations on TCE air concentrations in the shower room. As expected, predicted indoor air concentrations are highly sensitive to water concentrations. Figure II shows that as the water concentration increases from 15 μg/l to 75 μg/l (a factor of five), air concentrations also increase by about a factor of five or more. As the air exchange rate increases from 0.5 hr^{-1} to 1.5 hr^{-1}, indoor air concentrations are

predicted to decrease, and the differences between air levels become increasingly large with time.

Figure III shows the impact that different shower water temperatures have on indoor air concentrations. As water temperature increases, predicted air concentrations increase. After the shower has been on for 60 minutes, every 5°C increase in water temperature increases indoor TCE air levels by approximately 0.08 mg/m^3. For shorter shower durations, however, the effect of changing temperature is less pronounced, with every 5°C increase in water temperature increasing indoor air concentrations by approximately 0.03 mg/m^3 at 20 minutes and 0.02 mg/m^3 at 10 minutes.

These results indicate that the model presented in this paper behaves as expected; it predicts that indoor air levels increase as water concentrations increase, air exchange rates decrease, and water temperatures increase. The effects of changing these variables become increasingly important with time after the shower has been turned on. However, for short shower durations (e.g., less than 20 minutes), water concentration appears to have a greater impact on indoor air levels than air exchange rate or water temperature. In addition, the increase in air concentration with time appears to be approximately linear for short shower durations.

MODEL APPLICATION III. COMPARATIVE RISK ASSESSMENT

In order to estimate potential human VOC inhalation exposures and risk from showering, we applied our model to five VOCs that have been found in U public water supplies:[4,14] TCE, chloroform, tetrachloroethylene, vinyl chloride, and benzene. Benzene and vinyl chloride have been classified b as Group A carcinogens—human carcinogens based on adequate evidence fro human studies. The remaining three chemicals have been classified as G carcinogens—probable human carcinogens based on inadequate evidence fr human studies and adequate evidence from animal studies. Two plausible exposure scenarios were evaluated. The two scenarios differ with respect three variables: water concentration, shower duration, and air exchange rate. For the lower bound exposure scenario, the water concentration, sh duration, and air exchange rate were assumed to be 15 μg/l, 10 minutes, a 1.5 hr^{-1}, respectively. For the upper bound exposure scenario, the value for these three variables were assumed to be 75 μg/l, 15 minutes, and 0.5 hr^{-1}, respectively. Table III summarizes the input parameters used in this comparative risk assessment. These exposure scenarios are clearly no applicable to all homes and individuals, but they are probably representati of conditions that may exist in some homes in the United States.

Figure IV compares the estimated exposures for the five VOCs. The predicted exposures for the upper bound exposure scenario are approximately order of magnitude larger than the exposures for the lower bound exposure scenario. The largest exposures are predicted for vinyl chloride, the VOC with the largest Henry's Law Constant and lowest molecular weight. The next largest exposures are predicted for benzene, a chemical with the next smalle molecular weight but the second smallest Henry's Law Constant. Both of thes chemical-specific parameters are important factors affecting exposure. This figure also shows that exposures received over an assumed five minute period in the shower room after the shower has been turned off are almost as large exposures received while showering for 10 or 15 minutes.

The potential excess upper bound lifetime cancer risks associated with these estimated exposures are shown in Table IV. These calculations assume that an individual takes one 10- or 15-minute shower per day for a 70-year lifetime. The excess lifetime risks are highest for chloroform, 2×10^{-5} and 2×10^{-4} for the lower bound and upper bound exposure scenarios, respectively. The predicted risks are lowest for tetrachloroethylene, 3×10^{-7} and 3×10^{-6}, respectively.

The risks associated with inhaling VOCs in the shower for the two exposure scenarios are compared in Table V to the risks associated with ingestion of tap water at the same water concentrations (15 µg/l and 75 µg/l). It is important to recognize that all the VOCs evaluated except chloroform are more potent by ingestion than by inhalation. In calculating ingestion exposures, it was assumed that an individual drinks 2 liters of water per day for a 70-year lifetime. Table V shows that the ingestion cancer risks range from the same order of magnitude as the inhalation risks to approximately two orders of magnitude greater than the inhalation risks. For example, the risks associated with ingestion of chloroform in drinking water are essentially the same as the risks associated with chloroform inhalation in the shower room. For vinyl chloride, the ingestion risks are about two orders of magnitude greater than the inhalation risks. Thus, for the specific shower exposure scenarios evaluated in this comparative risk assessment, the estimated risks associated with the inhalation of VOCs in the shower room may be as large as the risks associated with VOC ingestion, depending on the particular chemical.

SUMMARY AND CONCLUSIONS

A kinetic model which can be used to estimate inhalation exposures to VOCs in the shower, both while showering and after the shower has been turned off, has been presented in this paper. Inhalation exposures to VOCs are modeled by estimating the rate of VOC release from water into air, the buildup (shower on) and decay (shower off) of VOCs in shower room air, and the quantity of airborne VOCs inhaled while the shower is both on and off.

The model was validated with one set of experimental data for TCE presented by Andelman et al.[1] The predicted air concentrations compared very favorably with the experimental results. In subsequent model runs, the predicted air concentrations were observed to be particularly sensitive to changes in shower water concentration and air exchange rate, but, in comparison, less sensitive to changes in water temperature.

Potential risks associated with inhalation in shower room air of five VOCs that have been measured in U.S. drinking water supplies were estimated for two plausible exposure scenarios. The lower bound exposure scenario assumed a 15 µg/l water concentration, a 10 minute shower, and an air exchange rate of 1.5 hr^{-1}. The upper bound exposure scenario assumed a 75 µg/l water concentration, a 15 minute shower, and an air exchange rate of 0.5 hr^{-1}. All other input variables, except those that are chemical specific, were held constant. The exposures and excess lifetime cancer risks estimated for the upper bound exposure scenario were approximately one order of magnitude greater than the exposures and risks estimated for the lower bound exposure scenario. Excess upper bound lifetime cancer risks were highest for chloroform, ranging from 2×10^{-5} to 2×10^{-4} for the lower bound and upper bound exposure scenarios, respectively.

These inhalation risks were compared to the risks associated with daily ingestion of 2 liters of water per day at the same concentrations, 15 µg/l and 75 µg/l. For the specific shower exposure scenarios evaluated, the estimated inhalation risks in the shower room were equivalent to the risks associated with ingestion for chloroform, but were two orders of magnitude lower than the ingestion risks for vinyl chloride.

Based on this analysis, our model can be applied to estimate inhalation exposures to VOCs in shower room air. The model has been validated with one set of experimental laboratory data in this paper, but additional data, particularly collected in the home, is required to conduct a more thorough validation. Further research is also needed to characterize more accurately the model's input parameters.

ACKNOWLEDGEMENTS

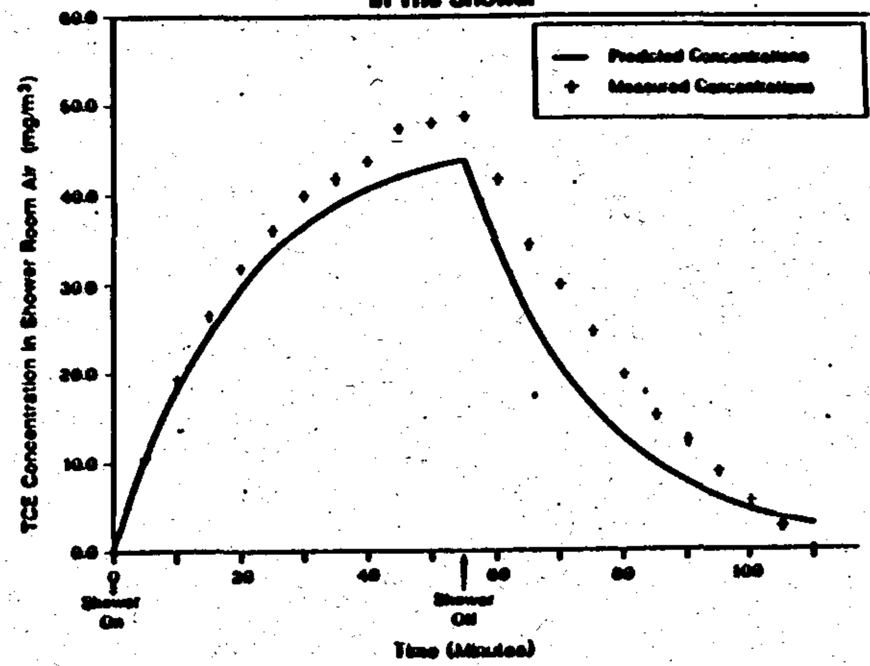
The authors would like to thank Jay Iurim for his review of the manuscript and the ICF-Clement word processing staff for typing the document.

Table 1. Model Application Using Experimental Data From Andelman et al.[1]

Input Parameter	Value
Andelman's data:	
Chemical	Trichloroethylene
Shower water concentration	2,000 μg/l[a]
Shower water temperature	43°C (316 K)
Shower water flow rate	0.3 l/min
Droplet diameter	0.25 mm
Droplet drop time	0.5 sec[b]
Air flow rate	0.005 m^3/min
Shower chamber volume	0.1 m^3
Shower duration	55 min
Duration after shower	56 min
Other model input data:	
Molecular weight	131 g/mol
Henry's Law Constant	1.0×10^{-2} atm-m^3/mol-K
Water viscosity	0.6178 cp

[a]Measured range 1,500-2,900 μg/l.
[b]Measured range 0.25-0.75 sec.

Figure I
Comparison Of Predicted And Measured* Trichloroethylene Air Concentrations In The Shower



*Source Of Measured Data: Andelman et al.[1]

Table II. Input Parameters for Sensitivity Analysis of Shower Room Air Concentrations

Input Parameter	Value: Figure II	Value: Figure III
Chemical	TCE	TCE
Molecular weight	131 g/mol	131 g/mol
Henry's Law Constant	1.0×10^{-2} atm-m^3/mol-K	1.0×10^{-2} atm-m^3/mol-K
Shower water concentration	15, 75 µg/l	75 µg/l
Shower water temperature	45°C	35°, 40°, 45°, 50°C
Water viscosity	0.596 cp	0.7194, 0.6529, 0.5996, 0.5468 cp
Shower water flow rate	10 l/min	10 l/min
Droplet diameter	1 mm	1 mm
Droplet drop time	2 sec	2 sec
Air exchange rate	0.5, 1.0, 1.5 hr^{-1}	1.0 hr^{-1}
Shower room air volume	6 m^3	6 m^3
Shower duration	60 min	60 min
Duration in room after shower turned off	60 min	60 min

Figure II

Effect Of Different Air Exchange Rates And TCE Water Concentrations On TCE Air Concentrations In The Shower

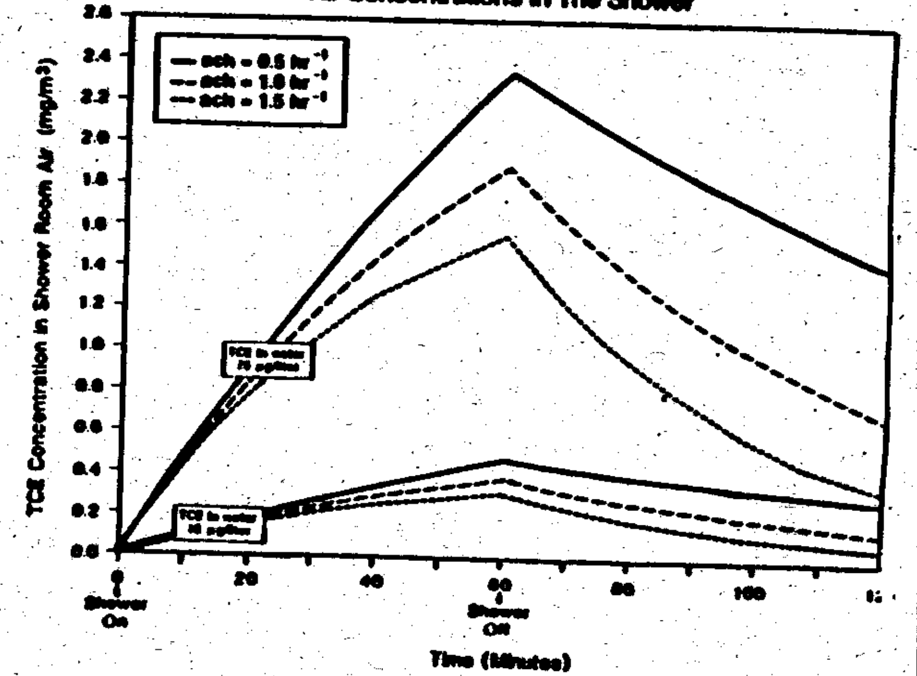


Figure III
Effect Of Different Water Temperatures On Trichloroethylene Air Concentrations In The Shower

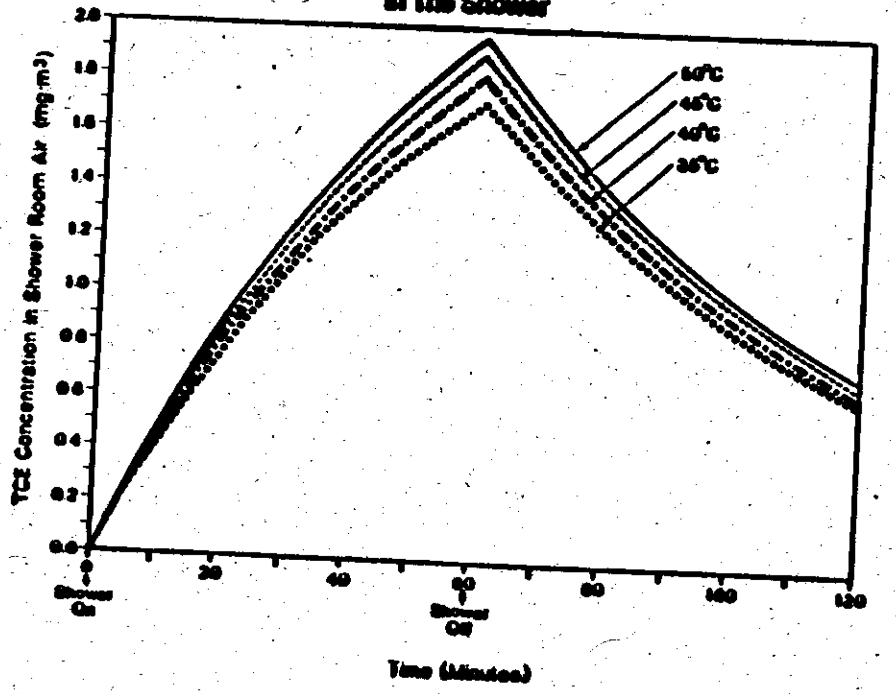


Table III. Input Parameters for Comparative Risk Assessment of Exposure to Five Volatile Organic Chemicals in Shower Room Air

Input Parameter	Value
Chemical (Henry's Law Constant, molecular weight)	Benzene (78 g/mol, 5.5×10^{-3} atm-m³/mol-K) Chloroform (119 g/mol, 2.87×10^{-3} atm-m³/mol-K) Tetrachloroethylene (166 g/mol, 2.6×10^{-2} atm-m³/mol-K) Trichloroethylene (131 g/mol, 1.0×10^{-2} atm-m³/mol-K) Vinyl chloride (63 g/mol, $(6.2 \times 10^{-2}$ atm-m³/mol-K)
Shower water concentration	75 µg/l (upper bound scenario) 15 µg/l (lower bound scenario)
Shower water temperature	45°C (318 K)
Water viscosity	0.596 cp
Shower water flow rate	10 l/min
Droplet diameter	1 mm
Droplet drop time	2 sec
Air exchange rate	0.5 hr^{-1} (upper bound scenario) 1.5 hr^{-1} (lower bound scenario)
Shower room air volume	6 m³
Shower duration	15 min (upper bound scenario) 10 min (lower bound scenario)
Duration in room after shower is turned off	5 min
Ventilation rate	15 l/min
Inhalation absorption factor	1.0
Body weight	70 kg
Cancer potency factor for inhalation [EPA weight of evidence classification for carcinogenic affects][a]	Benzene-2.6×10^{-2} $(mg/kg/day)^{-1}$ [A] Chloroform-8.1×10^{-2} $(mg/kg/day)^{-1}$ [B2] Tetrachloroethylene-1.7×10^{-3} $(mg/kg/day)^{-1}$ [B2] Trichloroethylene-4.6×10^{-3} $(mg/kg/day)^{-1}$ [B2] Vinyl chloride-2.5×10^{-2} $(mg/kg/day)^{-1}$ [A]

[a] [A] = human carcinogen based on adequate evidence from human studies; [B2] = probable human carcinogen based on inadequate evidence from human studies and adequate evidence from animal studies.

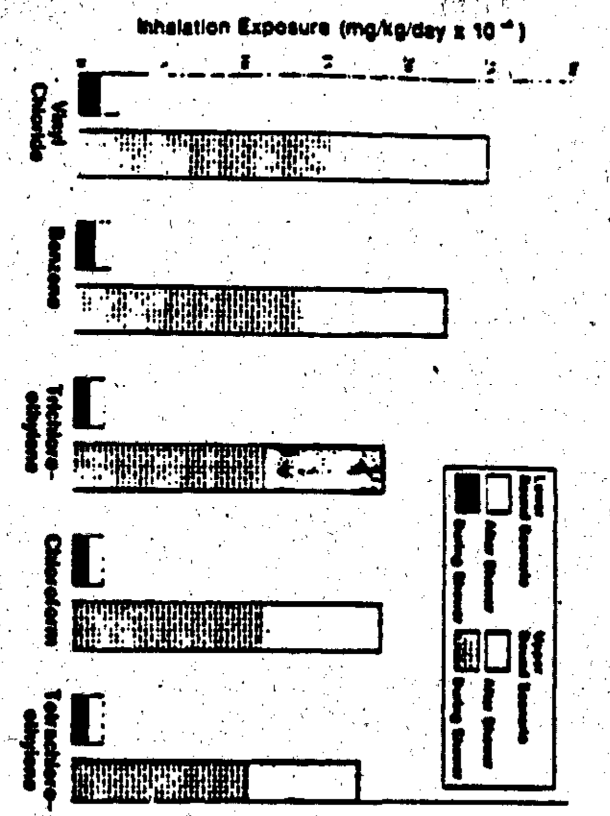


Figure IV
Comparison of Inhalation Exposures to Five Volatile Organic Compounds in the Shower

Table IV. Comparative Risk Assessment for Inhalation of Five Volatile Organic Compounds in Shower Room Air

Chemical	Exposure (mg/kg/day)[a] Lower Bound Scenario[b]	Exposure (mg/kg/day)[a] Upper Bound Scenario[c]	Cancer Potency Factor for Inhalation $(mg/kg/day)^{-1}$	Excess Lifetime Cancer Risk Lower Bound Scenario[b]	Excess Lifetime Cancer Risk Upper Bound Scenario[c]
Benzene	2.24×10^{-4}	2.26×10^{-3}	2.6×10^{-2} [A][d]	6×10^{-6}	6×10^{-5}
Chloroform	1.86×10^{-4}	1.88×10^{-3}	8.1×10^{-2} [B2][d]	2×10^{-5}	2×10^{-4}
Tetrachloroethylene	1.73×10^{-4}	1.75×10^{-3}	1.7×10^{-3} [B2][d]	3×10^{-7}	3×10^{-6}
Trichloroethylene	1.87×10^{-4}	1.89×10^{-3}	4.6×10^{-3} [B2][d]	9×10^{-7}	9×10^{-6}
Vinyl chloride	2.48×10^{-4}	2.50×10^{-3}	2.5×10^{-2} [A][d]	6×10^{-6}	6×10^{-5}

[a]Assumes one shower per day over a 70-year lifetime.

[b]Lower-case scenario: Water concentration = 15 μg/l, ach = 1.5 hr^{-1}, 10-minute shower, and 5 minutes in shower room after shower off. See Table III for all input parameter values.

[c]Upper-case scenario: Water concentration = 75 μg/l, ach = 0.5 hr^{-1}, 15-minute shower, and 5 minutes in shower room after shower off. See Table III for all input parameter values.

[d]EPA weight of evidence classification for carcinogenic effects (see Table III).

Table V. Comparison of Excess Lifetime Cancer Risks Associated With Inhalation of VOCs in Shower Room Air and Ingestion of VOCs in Tap Water

Chemical	Range of Excess Lifetime Cancer Risks[a] Inhalation[b]	Ingestion[c]
Benzene	6×10^{-6} - 6×10^{-5}	2×10^{-5} - 1×10^{-4}
Chloroform	2×10^{-5} - 2×10^{-4}	3×10^{-5} - 2×10^{-4}
Tetrachloroethylene	3×10^{-7} - 3×10^{-6}	2×10^{-5} - 1×10^{-4}
Trichloroethylene	9×10^{-7} - 9×10^{-6}	5×10^{-6} - 2×10^{-5}
Vinyl Chloride	6×10^{-6} - 6×10^{-5}	1×10^{-3} - 5×10^{-3}

[a]Lower value in range assumes water concentration = 15 μg/l; upper value in range assumes water concentration = 75 μg/l.

[b]Assumes one 10- or 15-minute shower per day for a 70-year lifetime. Detailed exposure conditions are shown in Table III.

[c]Assumes ingestion of 2 liters of water per day over a 70-year lifetime.

REFERENCES

1. Andelman, J.B. Human exposure to volatile halogenated organic chemicals in indoor and outdoor air. Env. Health Persp. 62:313-318 (1985).

2. Shehata, A.T. A Multi-Route Exposure Assessment to Chemically-Contaminated Drinking Water and Health Significance with Emphasis on Gasoline. Prepared for Maine Department of Environmental Protection. Bureau of Health. Maine Department of Human Services. January 1985.

3. Prichard, H.M., and Gesell, T.F. An estimate of population exposures due to radon in public water supplies in the area of Houston, Texas. Health Physics 41:599-606 (1981).

4. Cothern, C.R., Coniglio, W.A., and Marcus, W.L. Techniques for the Assessment of Carcinogenic Risk to the U.S. Population Due to Exposure from Selected Volatile Organic Compounds from Drinking Water via the Ingestion, Inhalation, and Dermal Routes. Office of Drinking Water, U.S. Environmental Protection Agency. EPA 570/9-85-001. 1985.

5. Symms, K.G. Approximation of the inhalation exposure to volatile organic chemicals from showering with contaminated household water. Presented at the 1986 American Society of Civil Engineers Annual Meeting. Boston, Massachusetts. October 27-31, 1986.

6. Andelman, J.B. Inhalation exposure in the home to volatile organic contaminants of drinking water. Sci. Total Environ. 47:443-460 (1985).

7. Bishop, B.L., Rosenman, K.D., and Patel, D.B. An Exposure-Risk Assessmen for Benzene in Shower Air. New Jersey Departments of Health and Environmental Protection. Presented at the American Public Health Association Annual Meeting, November 1984.

8. Foster, S.A., and Chrostowski, P.C. Integrated Household Exposure Model for Use of Tap Water Contaminated with Volatile Organic Chemicals. Paper 86-12.3. Presented at the 79th Annual APCA Meeting. Minneapolis, Minnesota. June 22-27, 1986.

9. Liss, P.S., and Slater, P.G. Flux of gases across the air-sea interface. Nature 247:181-184 (1974).

10. Lyman, W.J., Reehl, W.F., and Rosenblatt, D.H. Handbook of Chemical Property Estimation Methods: Environmental Behavior of Organic Compounds. McGraw-Hill, Inc. 1982.

11. O'Connor, D.J., and Dobbins, W. The mechanics of reaeration in natural streams. J. Sanit. Eng. Div., ASCE 82:SA6 (1956). In Schroeder, E.D. Water and Wastewater Treatment. Chapter 4: Gas Transfer. McGraw-Hill, Inc. 1977.

12. Andelman, J.B., Meyers, S.M., and Wilder, L.L. Volatilization of trichloroethylene and chloroform from an experimental bath and shower system. Presented before the Division of Environmental Chemistry, American Chemical Society. Anaheim, California. September 1986.

13. Wadden, R.A., and Scheff, P.A. Indoor Air Pollution. J. Wiley & Sons, Interscience. 1983.

14. U.S. Environmental Protection Agency. National Primary Drinking Water Regulations: Volatile Synthetic Organic Chemicals. Fed. Reg. 49:24330-24355 (1984).